GEOMETRICAL EFFECTS OF EXPLODING FILM ON PLASMA FORMATION

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Abstract

Metallized polypropylene films (MPPF) can serve as an alternate for exploding wires in many applications. Compared to wires, MPPF is more structurally robust and can be shaped more easily for specific applications. If long films are desired, the film can be shaped to fit a variety of geometries. In our experiments, MPPF as along as 13" have exhibited plasma formation. Experiments were performed to analyze the effect of the geometry of the film, and its orientation on transient plasma formation. Tests with flat geometries and semi-circular geometries were conducted. The results have been analyzed and are presented.

I. INTRODUCTION

The Energy Systems Institute, at the University at Buffalo, has electrically characterized the plasma properties of many different MPPFs of differing lengths and widths in a flat geometry [1]. An application was proposed where it would be necessary to substitute a comparatively longer piece of MPPF for an exploding wire. The film had to retrofit into an existing confinement. Therefore, this application required using a different geometry due to space limitations rather than the flat geometry that was previously studied. A semi-circular geometry was proposed because this geometry allows a longer piece of film to be shaped and placed into the established volume while obtaining the inherent benefits, such as reduced sensitivity to electrostatic discharge, of a longer piece of MPPF.

II. EXPERIMENTAL SETUP

All films that were tested had metallization on a single side of the film. When placed in the semi-circular geometry the metallization could be oriented so that the metallization was either facing outside or facing inside. During preliminary tests it was observed that metallization was completely removed from the film except for where the film made mechanical contact with the low and high voltage when the metallization was oriented in towards the inside. All data reported herein has the MPPF oriented such that the metallization faces in for the semi-circular geometry.

Four types of MPPF were tested in the semi-circular configuration to study the effect that the film's geometry had on plasma formation. All films used in this phase of tests were cut to a length of 5.08 cm (2 inches) and a width of 1.27 cm (0.5 inches).

Table 1 below summarizes the different film properties of the samples that were tested.

Table 1. Sample specifications.

Samples	Metallization Thickness	Substrate Thickness	Resistance
High resistance 7 micron	100 Å	7 micron	7 Ω/square
Low resistance 7 micron	250 Å	7 micron	1 Ω/square
5 mil	100 Å	5 mil	7 Ω/square
11.8 micron	225 Å	11.8 micron	1.5 Ω/square

The films that were tested were chosen because of their different physical properties, and the available data that was already generated by the Energy Systems Institute for these film samples in a flat geometry. The 5 mil film, for example, was chosen because of its substrate thickness while maintaining a similar metallization thickness and sheet resistance to other samples in the pool. Compared to the other three films, the 5 mil exhibited an inherent rigidity, but still allowed its orientation to be manipulated into a desired geometry easily.

Attempts were made to acquire other MPPFs that had a substrate thickness on the order of mils, but films with substrate thicknesses on the order of mils are not readily available commercially. The thickest film that could be reasonably obtained was the 11.8 micron MPPF. The 11.8 micron and the other two films tested in this phase have a much thinner substrate which affects their structural rigidity, and required more care in shaping the film into its desired geometry. Testing also revealed a quality issue with respect to the 11.8 micron film.

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14. ABSTRACT

Metallized polypropylene films (MPPF) can serve as an alternate for exploding wires in many applications. Compared to wires, MPPF is more structurally robust and can be shaped more easily for specific applications. If long films are desired, the film can be shaped to fit a variety of geometries. In our experiments, MPPF as along as 13 have exhibited plasma formation. Experiments were performed to analyze the effect of the geometry of the film, and its orientation on transient plasma formation. Tests with flat geometries and semi-circular geometries were conducted. The results have been analyzed and are presented.

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Fig. 1 is a schematic representation of the film in a semi-circular geometry for the experiments that were performed.

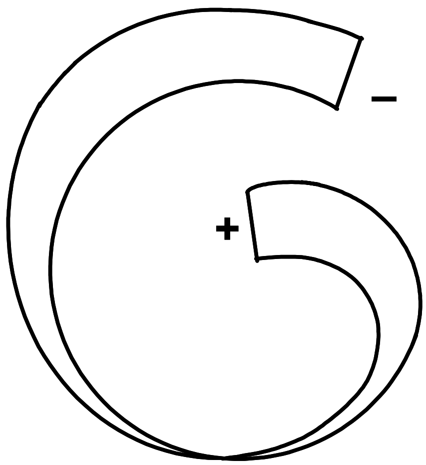

Figure 1. Schematic of semi-circular configuration.

A capacitive discharge power source, shown in Fig. 2, was used. The MPPF film sample acts as the load to the system.

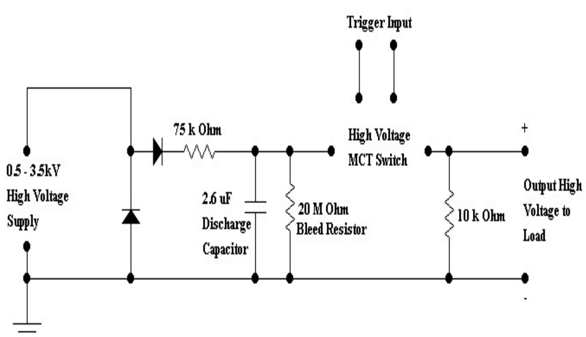

Figure 2. Schematic of capacitive discharge pulser.

The power source contains a 2.6 µF capacitor that discharges through an NMOS controlled thyristor into the film which acts as a load. Pearson type 411 current probes with conversion factors of 0.1 Volts/Ampere and 0.01 Volts/Ampere were used. A Tektronix P6015 voltage probe with an attenuation ratio of 1000:1 was also used. The current and voltage waveforms were captured on a Tektronix TDS7104 digital phosphor oscilloscope. The pulse was discharged across the sample through mechanical connections made at the center high voltage probe and the outer casing of the jig that acted as the low voltage probe. For all experiments, the capacitor was charged to a constant voltage of 2.5 kV_{dc}.

III. RESULTS

Testing that has been previously done on exploding film by the Energy Systems Institute has shown a correlation to certain current characteristics of an exploding wire. The most notable characteristics are the observation of an initial current strike, a dwell time, and then a re-strike of current. Fig. 3 is a typical current wave form for a uniform diameter exploding wire.

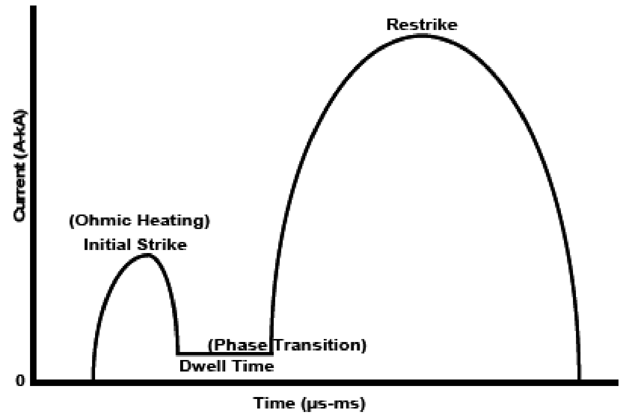

Figure 3. Typical current waveform for the uniform diameter exploding wire.

A current waveform of a MPPF sample that was exposed to the 2.5 kV_{dc} capacitive discharge is shown in Fig. 4. This particular sample had a length of 15.24 cm and a width of 0.32 cm, and was in a flat geometry. Fig. 4 is included to illustrate the typical waveform that was obtained during testing of samples with a length greater than 10 cm, and in a flat geometry. It should be noted that after the re-strike reaches its maximum the current level settles back to a non-conductive state.

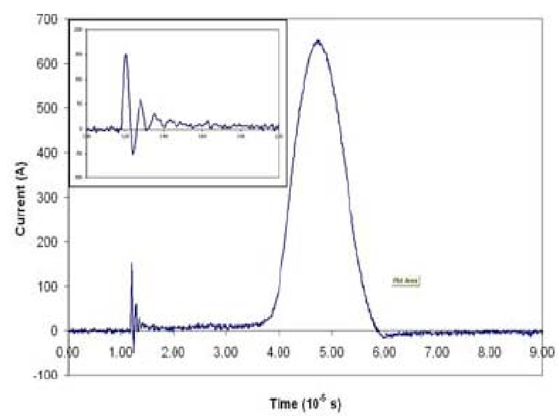

Figure 4. Current (A) vs. time (µs) low resistance 7 micron film in a flat geometry, Inset: initial strike detail.

These same characteristics were observed in this phase of testing with samples of shorter length, in both the flat and semi-circular geometry. There is a deviation however in that the current waveforms generated have ringing present after the re-strike occurs for both the flat and semi-circular geometry. The waveform in Fig. 5 is a typical result that was observed during testing.

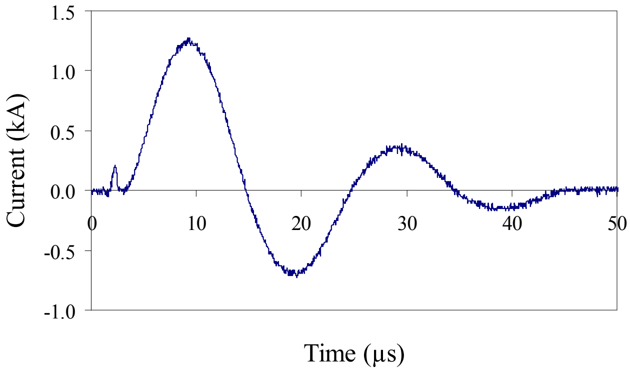

Figure 5. Current (A) vs. time (μs) high resistance 7 micron film in a semi-circular geometry.

A. Initial Strike

After the 2.5 kV_{dc} pulse is applied to the film sample, the current increases causing a time varying non-linear resistance as a result of ohmic heating [2]. Increased ohmic heating ultimately causes the aluminum metallization on the film sample to melt resulting in an increase in impedance. The resulting increase in impedance is illustrated by the decrease in the initial current strike to a condition of low conductance, or the onset of the dwell condition. As would be expected the initial current peak magnitudes are directly related to the sheet resistance reported in Table 1, except for the 11.8 micron MPPF.

The 11.8 micron film with a sheet resistance of 1.5 Ω/□ had a higher initial current than the low resistance 7 micron that has a lower sheet resistance. This result indicates that the quality of 11.8 micron film is suspect. In fact all results for the 11.8 micron film exhibited large standard deviations for all the electrical characteristics that were measured. Possible causes of this inconsistency could be aging of the film or oxidation of the metallization.

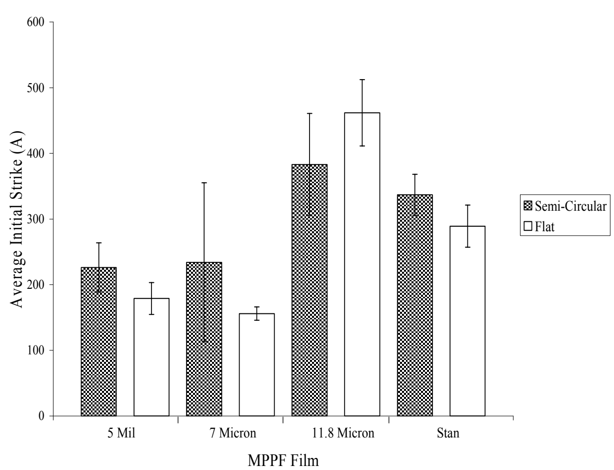

Figure 6. Initial strike current vs. film type and geometry.

B. Dwell Time

After ohmic heating has melted the aluminum, the phase transitions from a liquid to a gas. The dwell time is the period between the completion of the initial strike and the beginning of the current re-strike. During the dwell time any current that flows between the electrodes is now conducting only through a dense gas at a low, but constant current [3]. A dependency has been shown between the duration of dwell time and the length of an exploding wire [4].

Testing of MPPF samples in the flat geometry also revealed a correlation between sample length and dwell time. It has been observed that as the length of the sample decreases, the duration of the dwell time also decreases. Neglecting the suspect data for the 11.8 micron film, the geometry of the film seems to have an effect on the length of the dwell time. When the film is in the spiral geometry the dwell time increased. This is likely caused by the partial confinement of the gas that is inherent in the semi-circular geometry, increasing the time necessary for the gas to expand and transition to a plasma state.

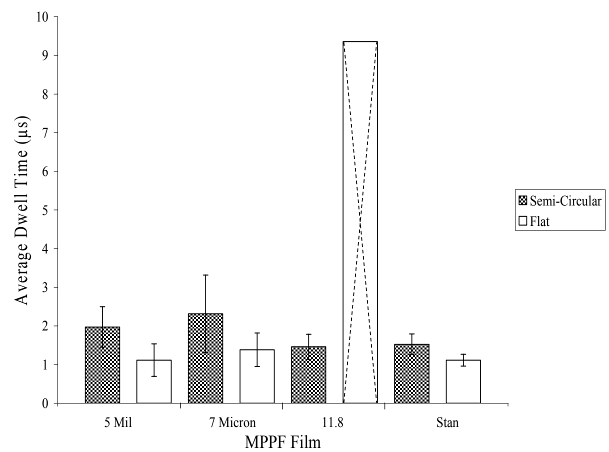

Figure 7. Dwell time vs. film type and geometry.

C. Restrike

After the expansion of the gas during the dwell time the aluminum vapor transitions to a plasma state. During this transition the pressure drops, the mean free path between collisions increases, and ionization by impact with attendant avalanche occurs [3]. Testing done at the Energy Systems Institute has shown a relationship between film length and re-strike current in a flat geometry [1]. This phase of testing shows a relationship between the film's geometry and re-strike current where the width and length of the film are held constant. When the film is oriented in a semi-circular geometry the amplitude of the re-strike current is consistently less than the re-strike current of films oriented in a flat geometry as illustrated by the bar graph in Fig. 8.

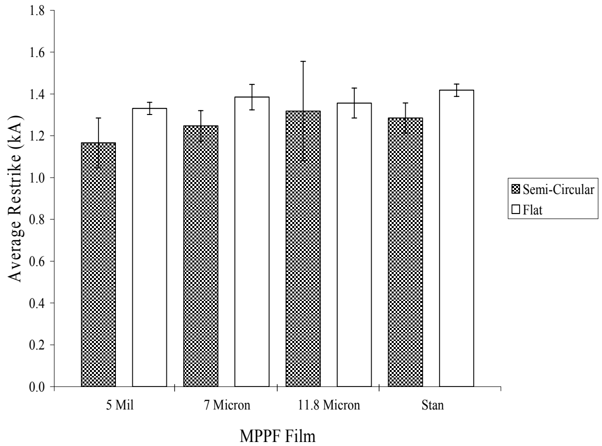

Figure 8. Re-strike current vs. film type and geometry.

The geometry's influence on re-strike amplitude likely can be explained by the orientation of the electric field when the sample is in the semi-circular geometry when compared to the orientation of the electric field when in the flat geometry. When the film is in the flat geometry the electric field and the re-strike current have the same general axial orientation. When the film is in the semi-circular geometry the electric field tends to be in a radial direction resulting in the plasma being exposed to a smaller component of the electric field in the direction of current flow. Fig. 9 illustrates the geometrical effect on the electric field.

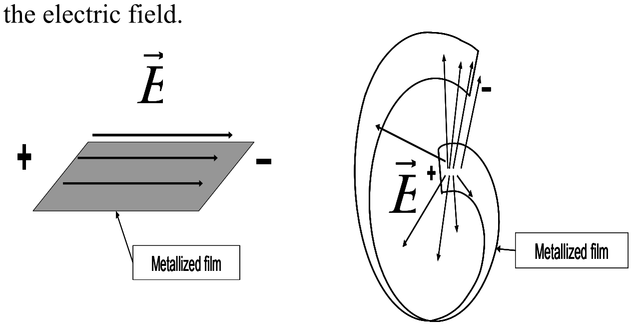

Figure 9. Geometrical influence on resultant electric field.

It can be shown that the energy of a charged particle in an electric field is:

$$W = \int (Q\vec{E}) \cdot \vec{v} dt \tag{1}$$

where W is work, Q is charge, E is the electric field, v is velocity, and t is time.

From Eq. (1) it is shown that the energy of a charged particle has a proportional relationship to the electric field. Therefore a larger electric field allows the electrons to pick up more energy from the electric field, which results in more ionization collisions, resulting in higher currents.

D. Total Duration

The total duration refers to the time interval that includes the initiation of the initial current strike, the dwell time, the re-strike, and concludes when the plasma is quenched and the current returns to 0 A. A relationship has been established between film length and total duration where the total duration increased with an increase in film length [1]. There did not seem to be a discernable relationship to the film's geometry.

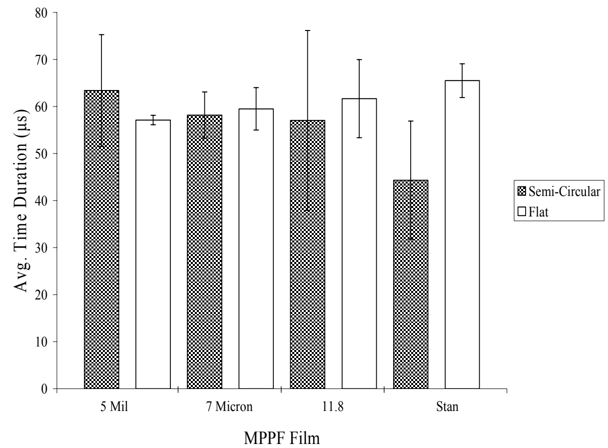

Figure 10. Total duration vs. film type and geometry.

E. Power

The average peak power was derived from the multiplication of the current and voltage waveforms. The results are consistent with the lower re-strike current that was observed for the semi-circular configuration.

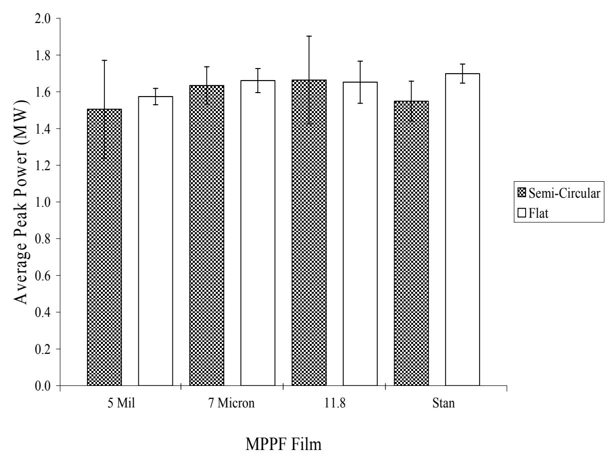

Figure 11. Average peak power vs. film type and geometry.

F. Energy

The average energy was computed using the voltage, current, and power waveforms and the results are presented in Fig. 12 on the following page. As expected the average total energy in the system decreased when the film was oriented in the semi-circular geometry.

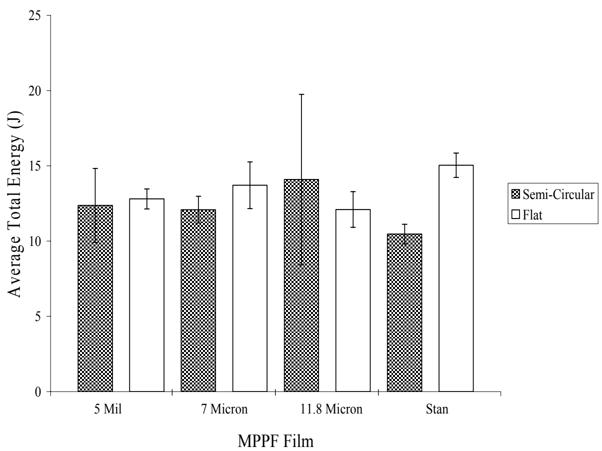

Figure 12. Average total energy vs. film type and geometry.

IV. CONCLUSION

This phase of testing on MPPF as an alternate for an exploding wire revealed that the geometry of the film has an effect on the electrical characteristics when exposed to a capacitive discharge. The decrease in re-strike current will have to be studied further because depending on the specific application this reduction in current could impact the operation of the system.

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